Multiphysics Modeling of Spring-Supported Thrust Bearings for Hydropower Applications

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Abstract: The present work is an attempt in predicting the performance of spring-supported thrust bearings. Thorough research has been done into the existing theories in order to incorporate them into the COMSOL Multiphysics software. The results proved the capability of coupling partial differential equations (PDE) to form a complex non linear system and thus obtaining proper results. The Reynolds equation is solved taking into account pad and collar elastic deformation and thermal expansion. The importance of including these phenomena has been evaluated. Linking the bearing material properties with the pressure and temperature developed in the assembly has been seen to play an important role. The result of this research is a hydrodynamic model taking into account the main variables involved in a spring-supported thrust bearing performance. The model developed can be used when designing or modifying thrust bearings.

Keywords: thrust bearings, Reynolds, spring-supported, elastic deformation, thermal expansion.

1. Introduction

The main feature of the thrust bearings is to provide for separation between the shaft and the support, something essential when working with hundreds of tones spinning at hundreds of revolutions per minute. A physical contact between both surfaces would represent the destruction of the machine.

A highly pressured, micrometre thin, lubricant film is located between the collar or runner (dynamic part) and the pad (static part). The static piece is compound from a number of segment shaped pads.

The most common type for hydropower applications are the tilting pad thrust bearings (TPTB). In this kind of thrust bearings, each pad is placed over a spherical pivot that allows tilt to the surface (Figure 1). A fixed defined pivot point restricts heavily the degrees of freedom of the pad.

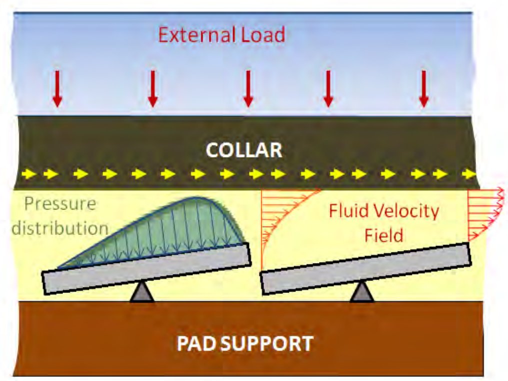


Figure 1. Tilting pad thrust bearings performance scheme.

To allow tilting and at the same time avoid this punctual fixed contact point, the spring-supported thrust bearings were created. This second kind of thrust bearings allows working under a wide range of operating conditions maintaining a good efficiency. The pads lie on a spring mattress that handles the applied load. The spring-supported thrust bearings follow the same principles, however with a different tilting system (Figure 2). The springs-supported thrust bearing has good self adjustment and heat dissipation. It is also of benefit with respect to vibration in running.

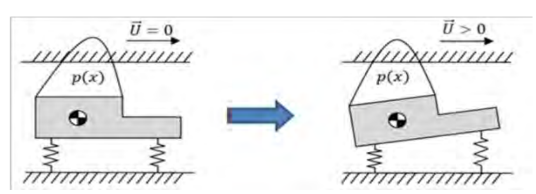


Figure 2. Spring supported thrust bearing performance.

It is well-known the argument between tilting-pad and spring-supported thrust bearings supporters. It is not clear which grants better results. Although the spring-supported has a not fix pivot point, the spring pattern hampers considerably its study.

The complexity of this kind of thrust bearings is mostly the strong linkage between all the phenomena involved from different engineering fields.

2. Model

The study carried out is a thermoelastohydrodynamic analysis (TEHD) which requires a high computational capacity to solve a complex FEM non lineal system (Figure 3).

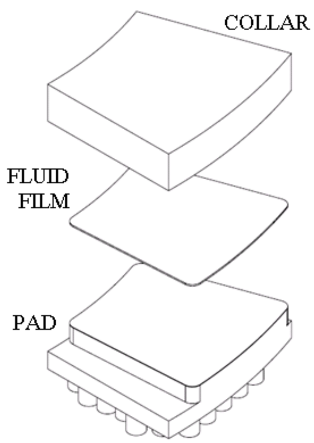


Figure 3. The three models required to predict spring-supported thrust bearing performance (pad, fluid film and collar).

2.1 Pressure Distribution: the Reynolds Equation

The pressure distribution on the thin lubricant film is obtained from solving the Reynolds Equation (Figure 4). The gap is small enough to use the Reynolds Equation instead of the general Navier-Stokes equation which would increase the complexity of the calculations.

The Reynolds Equations in 2D reads:

$$\nabla \cdot \left(\frac{\rho h^3}{12\eta} - \frac{1}{2} U \rho h \right) = 0$$

where ρ is the lubricant density, η is the viscosity, $\mathbf{U}$ is the collar velocity and h is the geometry of the gap between the pad and the collar. Lubricant density and viscosity varies with pressure and temperature and they have significant influence on system convergence. However, the parameter that influences convergence most is h, i.e., the gap morphology, which encompasses both mechanical deformation and thermal expansion.

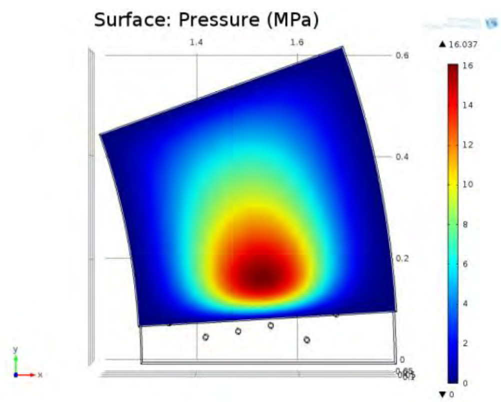


Figure 4. Pressure distribution on the pad surface.

As it is found in many rotor hydraulic machines, cavitation is a phenomenon to deal with when working with thrust bearings. Due to the divergent shape of some parts of the gap, huge negative pressure regions can be found when solving the Reynolds Equation. In the present model, the effect of cavitation is accounted for by simply using the positive part of the pressure distribution while integrating load carrying capacity.

2.2 Elastic Deformation

The pressure distribution in the fluid film is applied in the boundary conditions on the other models (pad, collar plate and lubricant film).

Here, the pad is modeled as a union of three different domains: a steel structure, the Babbitt layer and the foundation of springs. The materials of the pad and the Babbitt are specific for each thrust bearing and must be obtained from the manufacturer. In the present model, the springs are modeled as elastic cylinders with corresponding Young modulus and Poisson ratio adapted to actual spring data. The collar, normally made from a different material than the pad, has been also modeled here, with the fluid pressure contributing towards mechanical deformation and with convection & conduction contributing towards thermal expansion. Figure

5, depicts the total displacement, i.e. both mechanical deformation and thermal expansion, at a typical operating point.

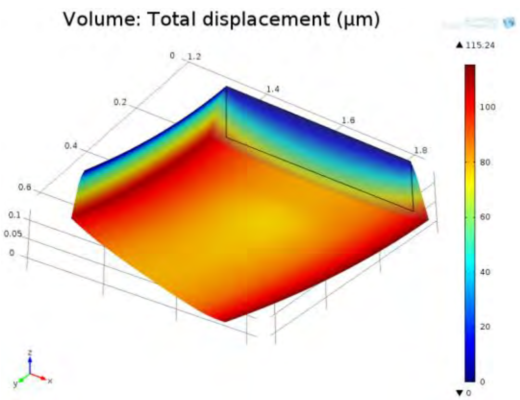


Figure 5. Collar deformation due to the pressure applied and the thermal expansion.

Notice that the displacement of the walls of the pad and the collar, changes the gap geometry h defined in the Reynolds Equation. This coupling substantially increases the non-linearity of the problem.

2.3 Temperature Distribution

The temperature plays an important role for the performance of the bearing. It is essential to take into account the thermal expansion of the solid geometries and the lubricant material proprieties variation with temperature; mainly the density and the viscosity of the fluid.

The temperature distribution in the fluid film is obtained from the definition of a Heat Transfer in Fluids physic in the fluid model (Figure 6):

$$\rho \cdot Cp \cdot \left(u_f \cdot \frac{\partial T}{\partial x} + v_f \cdot \frac{\partial T}{\partial y} \right) - k \cdot \frac{\partial^2 T}{\partial z^2} =$$

$$\eta \cdot \left[\left(\frac{\partial u_f}{\partial z} \right)^2 + \left(\frac{\partial v_f}{\partial z} \right)^2 \right] - \frac{T}{\rho}$$

$$\cdot \frac{\partial p}{\partial T} \cdot \left(u_f \cdot \frac{\partial p}{\partial x} + v_f \cdot \frac{\partial p}{\partial y} \right)$$

As explained, the pressure on the gap is obtained from solving the Reynolds Equation defined on the pad surface. The fluid velocity field $u=u(x,y,z)$, is also deduced from the pressure distribution;

$$\eta \cdot \frac{\partial u^2}{\partial z^2} = \nabla p$$

The temperature of the lubricant film governs the temperature of the whole assembly since the viscous heating is the only heat source included in the present study. The temperature in each node contributes to the thermal expansion of the pad and the collar.

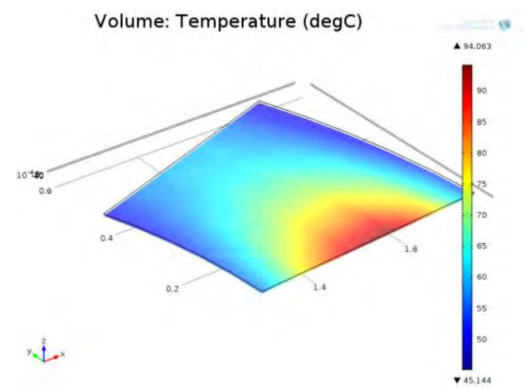


Figure 6. Temperature distribution of the fluid film.

3. Use of COMSOL Multiphysics

The most important governing equation defined in the current study is the Reynolds Equation. The equation is specified in the Lubricant Shell physics which is defined on the pad surface. A null boundary pressure is stated since this is a hydrodynamic approach. The velocity field of the moving walls it deduced from the angular velocity of the turbine and decomposed trigonometrically. The angular speed is left as an input parameter.

Another input parameter when working with turbines is the external load to handle (shaft and water weight). A global equation modeling the force balance between the generated pressure and the external load is introduced i.e.;

$$\int_{\partial\Omega} p dS = F_{fluid} = W_{ext}$$

Equality of this condition is reached by varying the average distance between the pad and the collar. This is achieved by means of the Lubricant Shell physics.

A Solid Mechanics physics is defined on the whole pad geometry. The pressure obtained from solving the Reynolds Equation is used as boundary load. A rigid surface is used to model the support for the elastic cylinders, modeling the spring foundation, so that it’s movement is restricted.

The last physics required for this spring-supported thrust bearing model, is the Heat Transfer in Solids physics. The temperature distribution of the top surface of the pad is obtained by solving the Energy Equation in the fluid model. On the other boundaries, convective cooling is imposed to take into account the heat transferred from the pad to the lubricant bath. In this way the temperature distribution in the solid is obtained, which in turn makes it possible to estimate the thermal expansion in the Solid Mechanic physics. Figure 7, shows the temperature of the pad.

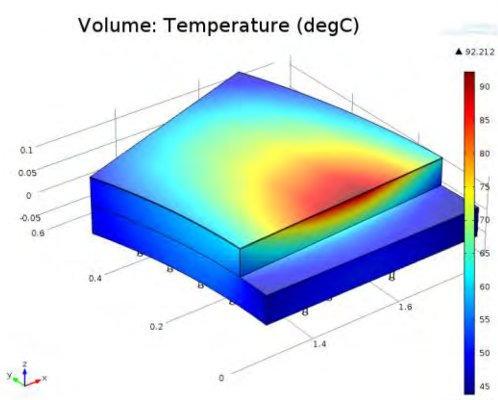


Figure 7. Temperature distribution of the pad.

The collar plate model follows the same principles as the pad. A Solid Mechanics physics is defined in which the fluid pressure acts as boundary load and the collar’s top surface is modeled as fixed.

A Heat Transfer in Solids physics is also defined in this model to obtain the temperature distribution in the collar and then estimate its thermal expansion. A uniform temperature is considered on the lower surface of the pad, due to its moving nature. It is considered the heat flux transferred from the fluid through the shaft.

The displacement field obtained from the pad and collar model confers precisely the gap geometry (Figure 8). Both displacements fields are included in the gap definition on the Lubricant Shell physics.

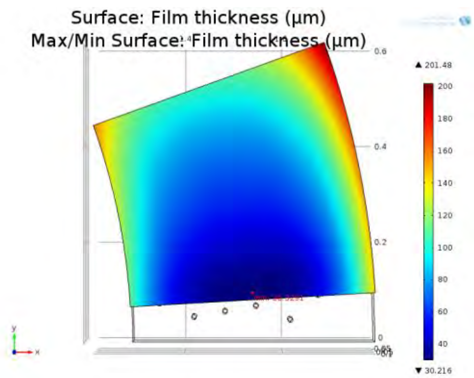


Figure 8. Fluid film thickness results from the combination of the pad and collar surfaces deformation.

A fluid model was necessary to consider the temperature increment. The Energy Equation is defined in the whole fluid domain. The velocity field can be deduced from the pressure distribution obtained in the Lubricant Shell. The heat source is determined from the shear stress suffered in the fluid film. In order to match the geometry of this model with the gap geometry, a Moving Mesh is defined in this geometry. The displacements of this mesh are obtained from the displacement fields of the pad and collar models. It has been necessary to define extrusion model coupling operators to use the different fields obtained in a model into another one.

4. Results

The final model is capable to combine the pad and runner displacement fields defining ideally the final gap morphology. These displacement fields from the solid compounds take into account the deflection suffered from the pressure applied and its counteraction by the thermal expansion. A large effort was spent to model the gap geometry due to its significance when solving the Reynolds equation. The model estimates also the temperature distribution, which depend on the bath temperature, the shaft rotational velocity, the external load applied and the bearing design. The model has been designed for pure hydrodynamic conditions; no hydrostatic elements have been input. The material proprieties, as confirmed by the simulations, play an important role. The model developed allows predicting e.g. overload situations, see Figure 9, test different kinds of lubricants, see Figure 10, or test the influence of different spring's distributions.

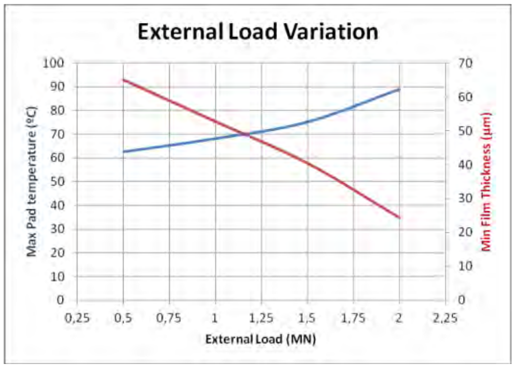
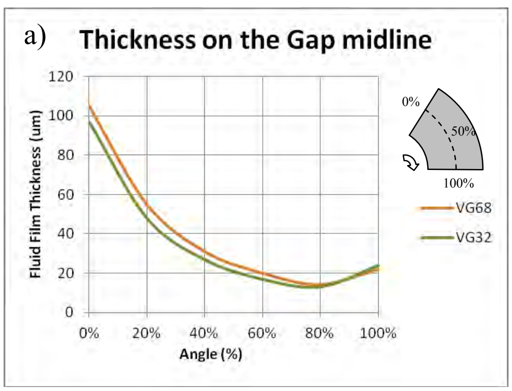


Figure 9. Variation of the film thickness and the pad temperature with external load.



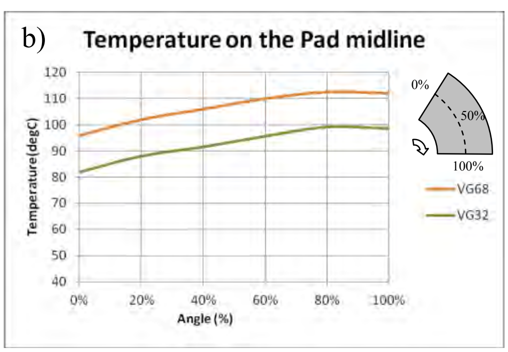


Figure 10. Comparison of a) film thickness, and b) pad temperature along the midline of the pad when using two different lubricants (ISO VG68, ISO VG32).

7. Conclusions

A model for spring-supported thrust bearings simulations has been developed. The true multiphysics model, efficiently couples the fluid flow, the fluid-solid interaction and the convection and conduction occurring within a typical spring-supported thrust bearing.

With special attention paid to applicability, the model was implemented in order to be easily adapted to a wide large class spring-supported thrust bearings. It allows for testing different lubricants, loads and speeds in order to predict the consequences of changing these. The model developed can be used to facilitate designing or modifying thrust bearings. It is also gives a better understating of the behaviour of this type of bearings.

8. References

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9. Acknowledgements

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